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Heavy Metals in the Water and Wastewater Systems of the University of Central Florida

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HEAVY METALS IN THE WATER AND WASTEWATER SYSTEMS OF THE UNIVERSITY OF CENTRAL FLORIDA

BY

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RESEARCH REPORT

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ABSTRACT

In large enough quantities, heavy metals may be detrimental to human health. Metals in raw water may pass through a water treatment plant without being completely removed. Once in the distribution system, the water may experience metal pick-up due to corrosion. During the course of this study, an attempt was made to determine the heavy metal concentrations in the University of Central Florida's potable water system.

Samples were run on the plasma spectrophotometer, Spectraspan III, and analyzed for heavy metal content. The results indicate pick-up of Fe, Al, Cu, and Zn in the distribution system. The arsenic and lead concentrations in the drinking water samples should be verified.

The UCF sewage treatment plant offers adequate heavy metal removal with the metal ions being removed concentrating in the activated sludge.

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CHAPTER I

INTRODUCTION

Federal legislation was passed in the late sixties and seventies to protect the quality of our waters. Concentrations of water constituents not exceeding limits specified by water quality criteria are expected to result in an aquatic ecosystem suitable for the higher uses of water. These criteria were developed from data obtained from research depicting organism responses to a defined stimulus or material under identifiable or regulated enviromental conditions for a specified length of time.

Water quality criteria are not intended to give the same degree of survival and propagation at all times to all organisms in an ecosystem. Instead, they are intended to protect significant and essential life in water as well as the direct users of water. It is also intented to protect life that is dependent on life in water for its existence or which may consume edible portions of aquatic life.

The domestic water supply criteria recommend maximum permissible levels based on available data for human health protection. These values are different from the levels necessary for the protection of aquatic life. In 1975 the National Interim Primary Drinking Water Regulations were published in accordance with the

provisions of the Safe Drinking Water Act (Public Law 92-523). These regulations incorporated applicable domestic water supply criteria. Where pollutants are identified in both the domestic water supply quality criteria and the Drinking Water Standards, the concentration levels are identical.

Of the 103 known elements, 83 of these are metals. Metals are generally distinguished by their luster, malleability, conductivity, and ability to form positive ions. Sixty-eight of these metals have a density five times greater than water and are classified as heavy metals. Heavy metals include all metals with atomic number greater than 23 except rubidium, strontium, yttrium, cesium, barium, and francium. (Zemansky, 1974).

Heavy metals in drinking water can result from pollutants discharged to the natural environment and/or ions released through the distribution system by corrosion. Corrosion may occur as a result of the instability of water. Corrosive waters are normally soft, however, hard water may produce calcium deposits in the system. Maximum contaminant levels for inorganic chemicals such as Arsenic, Cadmium, Chromium, Lead and others were established. Limits for those contaminants were established on the basis of threshold levels at which there were no adverse health effects. The State of Florida Department of Environmental Regulation has adopted the same federal limits for inorganic contaminants as shown by the rules of the

Public Drinking Water Systems, Chapter 17-22 which were filed with the Secretary of State, October 19, 1977.

Tables 1, 2 and 3 summarize the sources, average concentrations, drinking water standards, and health effects, respectively, of various contaminants in water.

Water treatment plants may or may not remove all of the trace heavy metals from the water before it is introduced into the distribution system. Once inside the water distribtuion system, inorganic contaminants may be released into the water as a result of internal corrosion. Internal corrosion is a multi-faceted problem involving aggressive water, galvanic cells (dissimilar metals in contact), hydraulic erosion, and electrolytic corrosion. Contaminants released and the mechanisms involved must be identified if corrective measures are necessary. Unfortunately, studies investigating changes in water quality as it flows through the distribution system are scarce or non-existent. There has been much concern over changes in the biological quality of drinking water but little is being done to study changes in inorganic contaminants. Extensive research is necessary to identify the corrosion problems and develop adequate management techniques to control these problems.

The inorganic pollutants released in the water distribution system will be ultimately transported to wastewater treatment facilities. Their fate during treatment processes is of particular

interest to those interested in preserving our natural water resources. Concern over concentrations of heavy metals in wastewater sludges has been expressed by scientists and researchers. These contaminants affect the methods of handling and disposing of sludge and its usefulness as a resource.

TABLE 1

GENERAL SOURCES OF VARIOUS METALS

Contaminant	Common Valance Form	Most likely occurance and source of contaminant
Arsenic	+3 (Arsenite) +5 (Arsenate)	groundwater-natural occurance surface water-natural occurance or industrial pollutant
Cadmium	+2	surface water-industrial pollutant
Calcium	+2	natural occurance to industrial waste
Chromium	+3 +6	groundwater-natural occurance surface water-industrial pollutant
Copper	+2	surface water-industrial pollutant groundwater-natural occurance
Iron	+3	natural occurance
Lead	+2	surface water-industrial pollutant
Magnesium	+2	natural occurance
Nickel	+2	surface water-industrial pollutant
Zinc	+2	surface water-industrial pollutant groundwater-natural occurance

SOURCE: U.S. Environmental protection Agency, Manual of Treatment Techniques for Meeting the Interim Primary Drinking Water Regulations (Cincinnati, Ohio, 1977): p. 3.

TABLE 2

AVERAGE CONCENTRATIONS OF VARIOUS METALS
DETECTED IN VARIOUS SYSTEMS

Metal	Concentration				
	Surface water µg/l	Water treatment plant effluent µg/l	Distribution system µg/l	Mean daily* intake, µg	Maximum permissible level, µg/l
Arsenic	10.0	------	------	------	50.0
Cadmium	9.5	12.0	1.3	2.6	10.0
Chromium	9.7	7.5	2.3	4.6	50.0
Copper	15.0	4.3	134.5	269.0	[1000.00]
Iron	52.0	68.9	166.5	333.0	[300.00]
Lead	23.0	33.9	13.1	26.2	50.0
Nickel	19.0	34.2	4.8	9.6	------
Zinc	64.0	79.2	193.8	387.6	[5000.00]
#samples analyzed	1577	380	969		

SOURCES: National Research Council, Drinking Water and Health (Washington, D.C., 1977): p. 210-11; G. F. Craun and L. J. McCabe, "Problems Associated with Metals in Drinking Water" Journal of the American Water Works Association 67 (November 1975): 597; U. S. Environmental Protection Agency, Quality Criteria For Water (Washington, D.C., 1976).

*assuming 2 liters/day/capita consumption

[ ] denotes secondary standard

TABLE 3

GENERAL HEALTH EFFECTS OF VARIOUS METALS

Contaminant	Health Effects
Arsenic	extremely toxic, cumulative poison, may be carcinogenic, can cause liver and heart ailments, death
Cadmium	toxic, gastrointestinal upsets, cramps, nausea, vomiting, diarrhea, cumulative poison death
Calcium	necessary element, excessive amounts can lead to kidney stones, reported that high calcium is associated with low cardiovascular disease, insufficient calcium in diet can cause rickets
Chromium	large dose leads to corrosive effects in the intestinal tract and to nephritis, causes nausea, can cause death
Copper	essential for nutrition, large doses can cause gastroenteritis, can cause discoloration of skin and hair, no evidence of copper poisoning from drinking water
Iron	essential for nutrition
Lead	cumulative poison, causes constipation, loss of appetite, anemia, abdominal pain and tenderness, pain and gradual paralysis of muscles, especially the arms, can cause death
Magnesium	essential mineral element, relatively non-toxic, has a laxative effect
Nickel	very low toxicity to humans
Zinc	essential for nutrition, very high concentrations can cause nausea and fainting

SOURCE: California, State Water Quality Control Board, Water Quality Criteria, by J.E. McKee and H.W. Wolf, Publication No. 3-A (Sacramento, California, 1963).

Scope and Objectives

The broad objective of this research report is to study changes of heavy metal concentrations in water samples collected from the University of Central Florida (UCF) Water Distribution System.

Water samples were collected from the UCF potable water intake wells, various campus buildings and influent and effluent points at the UCF wastewater treatment plant.

A sampling schedule and locations were developed and coordinated with the UCF physical plant personnel. Each site was sampled approximately once every 2 weeks. Samples were collected, filtered, digested, and analyzed as recommended by the Standard Methods for Examination of Water and Wastewater. Filterable and non-filterable fractions of heavy metals in the samples collected were measured using the plasma spectrometer Spectraspan III. Elements measured were Arsenic, Cadmium, Chromium Aluminum, Copper, Iron, Lead, Nickel, and Zinc. Calcium and Magnesium were also analyzed.

The differences between the water quality of samples collected from the intake wells and distribution system reflect the location and type of corrosion problem. The fate of inorganic contaminants through the treatment processes at the UCF wastewater treatment plant will aid to evaluate the efficiency of treatment processes for removal of heavy metals.

CHAPTER II

LITERATURE REVIEW

Trace metals in drinking water are suspected of being related to cardiovascular disease and other health problems. Metals may pass through a water treatment plant without being removed and may show an increase in concentration due to corrosion in the distribution system before reaching the consumer's tap.

The metals passing through the treatment plant and added to the water in the distribution system will eventually end up in a wastewater treatment plant. The heavy metals are largely concentrated in the sludge and this can lead to adverse effects and complicate problems associated with handling and disposal of sludges.

Health Effects

Soft water is generally more corrosive than hard water and should therefore contain more metal contaminants from water piping than would hard water. Metals commonly found in soft water are lead, cadmium, zinc, and copper, while metals found in hard water are usually iron, manganese, and lithium. Hard water also contains greater amounts of calcium and magnesium than soft water. (Craun & McCabe, 1975)

Neri et al (1975) found that soft water tends to pick up elements from the distribution system in a corrosive type of action, but hard water may lose elements in coating type of action. He also

found that lead, mercury, and copper are found in greater amounts in soft water than hard, while cobalt and chromium concentrations tend to increase as hardness increases. Nickel and cadmium concentrations were found to be unaffected by the amount of hardness present.

Kobayashi (1957) showed a correlation between cerebrovascular mortality and the acidity of waters in Japan. Other investigators have presented evidence which supports hypotheses that areas with hard waters tend to have lower death rates and less cardiovascular disease than soft water areas.

In 1975, Neri and associates conducted intensive investigations into the health aspects of hard and soft waters. Included in their work were analyses of heart tissues, epidemiologic investigations, and supervision of collection of cardiovascular disease (CVD) rate and water quality data in Canada. They concluded that there appeared to be an inverse curvilinear relationship between hardness and mortality rates. Their biopsy studies indicated that magnesium was most responsible for the relationship between CVD and water hardness.

Craun and McCabe (1975) presented data in an article relating cardiovascular death rates and water quality as shown in Table 4. Likewise, Hudson and Gilcreas (1976) presented the data shown in Table 5, which indicates that average CVD rate decreased with increasing hardness concentration. Hudson and Gilcreas concluded that cardiovascular disease rate was higher in areas where soft water was

TABLE 4

THE EFFECT OF DRINKING WATER DISSOLVED SOLIDS CONCENTRATION ON CARDIOVASCULAR DISEASE RATES

POPULATION	Mineralization of Drinking Water Dissolved Solids mg/l		
	0-99	100-199	200+
Male-White			
Diseases of the cardio-vascular system	643	616	583
Diseases of the heart	517	478	436
Vascular lesions CNS	90	100	105
General arteriosclerosis	21	23	24
Hypertension w/o heart	7	8	9
Other circulatory diseases	6	6	7
Female-White			
Diseases of the cardio-vascular system	446	406	361
Diseases of the heart	330	282	237
Vascular lesions CNS	87	94	93
General arteriosclerosis	17	18	19
Hypertension w/o heart	7	7	7
Other circulatory diseases	4	4	4

SOURCE: G. F. Craun and L. J. McCabe, "Problems Associated With Metals in Drinking Water," Journal of the American Water Works Association 67 (November, 1975): 597, table 1.

used and decreased in hard water areas. However, they did not consider the possibility of a relationship between cardiovascular disease and trace heavy metals which may have been present in the water supply. This was made evident by Abel Wolman (1976) in his opinion of Hudson and Gilcreas' paper. Wolman, (1976) stated that Lilienfeld is of the opinion that a trace metal in the drinking water may be related to heart disease and an intensive study will be required to confirm it.

TABLE 5

EFFECT OF HARDNESS ON CARDIOVASCULAR DISEASE RATES

Hardness range (mg/l as $CaCO_3$)	Number of cities in group	Average hardness for group	Average CVD case for group
0-49	22	24	430
50-99	28	77	400
100-149	27	120	400
150+	19	245	348

SOURCE: H. E. Hudson, Jr. and F. W. Gilcreas, "Health and Economic Aspects of Water Hardness and Corrosiveness," Journal of the American Water Works Association 68 (April, 1976): 202, table 1.

Punsar et al (1975) showed that coronary heart disease was associated with low concentrations of chromium and high concentrations of copper.

Neri et al (1975) presents a schematic showing the relationship of trace metals involved in cardiovascular function as presented in Figure 1.

Sources of Metals in Drinking Water

Some metals occur in natural waters as the result of geochemical pollution due to erosion of some metals such as arsenic, barium, and selenium. Other metals such as mercury may result primarily from industrial waste and municipal sewage.

A major source of metal contamination to drinking water is the water supply system. Metals in incoming raw water may pass through

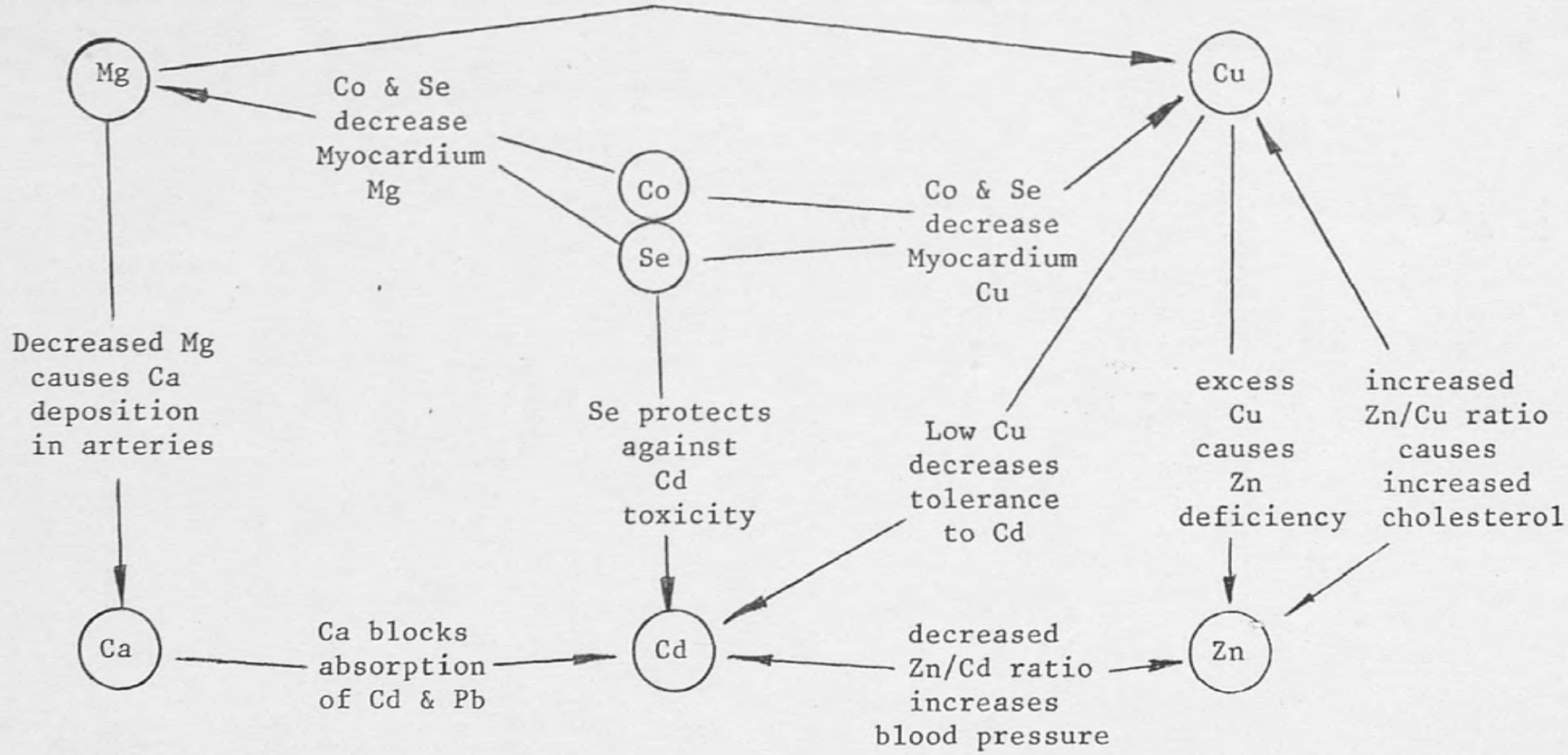


Fig. 1. Relationship of trace metals involved in cardiovascular function

SOURCE: L. C. Neri, et al., "Health Aspects of Hard and Soft Waters," Journal of the American Water Works Association 67 (August, 1975): 407, Fig. 1.

a treatment plant without being completely removed. For example, the use of copper and other chemical treatment for algae control in reservoirs may become a source of heavy metals in an area's drinking water.

Corrosion of the distribution system and household plumbing can contribute significantly to the metal content of drinking water. Corrosive waters increase the rate of metal pickup. Studies were done in Seattle and Boston (Dangel, 1975 and Craun & McCabe, 1975). Both Boston and Seattle use water from surface reservoirs and provide chlorination as the only treatment. Seattle also fluoridates its water with H_2SiF_6. The quality paramaters taken on treated water at the source are shown in Table 6.

TABLE 6

WATER QUALITY PARAMATERS FOR TREATED DRINKING FROM BOSTON AND SEATTLE

PARAMATER	CITY	
	BOSTON	SEATTLE
Ph	6.7	5.5
Hardness (mg/1 as $CaCO_3$)	14	--
TDS (mg/1)	50	--
Alkalinity (mg/1 as $CaCO_3$)	8	2
Chlorides (mg/1)	12	1.7
Calcium (mg/1)	--	2.1
Magnesium (mg/1)	1.0	0.3
Conductivity	60	20

SOURCE: G. F. Craun and L. J. McCabe, "Problems Associated with Metals in Drinking Water," Journal of the American Water Works Association 67 (November, 1975): 595.

Both cities' waters are soft and acidic. The distributed waters are good solvents and exhibit aggressive corrosion tendencies.

Standing samples and running samples were collected. Standing samples were the first waters to run out of the faucet and represented water which had a long residence time in the household plumbing and service line. Running samples were collected next, after insuring the house lines were well flushed and represented water from the mains. Standing water samples showing a higher concentration of metals than the running water samples were used as evidence of metal pickup. In Boston, a large percentage of the homes sampled had lead pipes while in Seattle, copper and galvanized iron pipes were the most common. No lead pipes were reported in Seattle and the lead was assumed to come from the solder used to join the copper piping. The results from the investigations are summarized in Table 7.

In Boston it was found that as the lead in the drinking water increases, a greater number of individuals consuming the water were found to have high amounts of lead in their blood. This tends to support the conclusion that the lead in the drinking water of Boston area residents is present in a large enough concentration to affect the human body burden of lead (Craun & McCabe, 1975).

The Community Water Supply Survey (McCabe et al., 1970) collected 2595 tap water samples covering 969 water systems located in 9 geographic areas around the country. All samples were analyzed for

TABLE 7

HEAVY METAL CONCENTRATIONS IN BOSTON AND SEATTLE DRINKING WATER

CITY	ELEMENT	Running Samples				Standing Samples				% Samples		No. of Samples Analyzed
		Max Conc. µg/l	Mean Conc. µg/l	Standard Deviation	Number Samples	Max. Conc. µg/l	Mean Conc. µg/l	Standard Deviation	Number Samples	Showing Pick-Up	Exceeding Standards	
SEATTLE	Cd	.8	.3	.1	28	25	2.5	5.2	28	61	7	
	Cu	1670	160	350	22	2050	450	610	22	73	24	
	Fe	1200	270	220	21	5400	1400	1300	21	86		31
	Pb	17	5	4	22	170	39	49	22	95	0	
	Mn	23	11	4	22	79	24	17	22	82	5	
	Zn	1730	230	380	21	5460	1740	1520	21	95	10	
BOSTON	Cd	8	1.0	1.4	54	5	.7	1.0	54	13	0	
	Cr	8	3.1	1.9	54	8	3.4	1.8	54	39	0	
	Cu	1540	432	298	54	2410	494	504	54	44	19	54
	Fe	560	141	116	54	442	142	83	54	52	9	
	Pb	241	58	49	54	321	80	78	54	30	65	
	Mn	34	24.6	4.8	54	42	25.4	2.9	54	11	0	
	Zn	1625	223	333	54	791	148	203	54	35	0	

SOURCE: C. F. Craun and L. J. McCabe, "Problems Associated with Metals in Drinking Water," Journal of the American Water Works Association 67 (November, 1975): 595-60, Table 2.

heavy metals using the atomic absorption spectrophotometer and the results were as shown in Table 8.

TABLE 8

HEAVY METAL CONCENTRATIONS IN TAP WATER

ELEMENT	CONSTITUENT LIMIT (mg/l)	MAXIMUM CONC. FOUND (mg/l)	# OF SAMPLES EXCEEDING LIMIT	% EXCEEDING LIMIT
Arsenic	0.01	0.10	10	.4
Copper	1.0	8.35	42	1.6
Iron	.3	26	223	8.6
Manganese	.05	1.32	211	8.1
Cadmium	.01	3.94	4	.2
Chromium (hexavalent)	.05	.079	5	.2
Lead	.05	.64	37	1.4
Selenium	.01	.07	10	.4
Silver	.05	.03	0	0
Zinc	5.0	13	8	.3

SOURCE: L. J. McCabe, et al., "Survey of Community Water Supply Systems," Journal of the American Water Works Association 62 (November, 1970): 681, Table 15.

A later survey (McCabe, 1974) of 273 communities was taken for mercury contamination. Ninety-six percent of the communities sampled had less than 1.0 µg/l of mercury.

It is the opinion of most investigators that man's major source of trace metals is his food intake. Murthy (1971) studied the intake from food used in institutional diets for children aged 9 to 12. A comparison was made between this and Community Water Supply Survey,

(Craun & McCabe, 1975), and is shown in Table 9.

TABLE 9

COMPARISON OF TRACE METAL INTAKE BETWEEN WATER SOURCES AND FOOD SOURCES

ELEMENT	% intake due to	
	water source	food source
Zinc	4.3	95.7
Cadmium	3.3	96.7
Manganese	2.8	97.2
Cobalt	.4	99.6
Chromium	.8	99.2

SOURCE: G. F. Craun and L. J. McCabe, "Problems Associated with Metals in Drinking Water," Journal of the American Water Works Association 67 (November, 1975): 596.

Hammer et al. (1971) has shown that the analysis of tissue such as hair, nails, blood and teeth is an expedient method of measuring human body burdens for heavy metals. Data from a pilot study by Craun and McCabe (1975) has shown that even though a person's intake of iron and manganese from water is relatively low when compared with food, gradients of iron and manganese have been observed in scalp hair in populations using different water supplies. Craun and McCabe (1975) estimated the average intake of metals from community water supplies assuming 2 liters per person per day consumption rate, as presented in Table 10.

TABLE 10

ESTIMATED AVERAGE DAILY INTAKE OF METALS

ELEMENT	AVERAGE CONC. ug/l	MICROGRAMS INTAKE	PERCENTAGE OF SAMPLES WITH 1 ug/l or more
Cadmium	1.3	3	63
Chromium	2.3	5	11
Cobalt	2.2	4	62
Copper	134.5	270	99
Iron	166.5	330	99
Lead	13.1	26	74
Manganese	22.2	44	78
Nickel	4.8	10	78
Silver	.8	2	23
Zinc	193.8	390	100

SOURCE: G. F. Craun and L. J. McCabe, "Problems Associated with Metals in Drinking Water," Journal of the American Water Works Association 67 (November, 1975): 597, Table 3.

Corrosion

Corrosion is an attempt by a metal to return to its most stable state. Corrosion processes are usually complex interactions among metalurgical, physical and chemical aspects of a structure and its environment. Water distribution system corrosion involves the internal corrosion of pipes and conduits due to flowing, aerated water containing dissolved minerals in near-neutral solutions. Control of this type of corrosion is normally accomplished by the use of precipitating inorganic inhibitors. Also, the exterior surfaces of

pipes are subject to soil corrosion due to chemical and baterio logical attack and "stray currents." (Weber, 1972). The review of corrosion in this paper will be limited to that which occurs in the interior of the pipes.

The Corrosion Reaction

A reasonable analog model of the corrosion of metals in water is a dry cell battery. The cell is composed of two electrodes separated from one another by an electrolyte. A chemical reaction occurs at the cathode and chemical oxidation at the anode. Chemical reactions at each electrode generate electrical energy. The more intense the reactions the greater the current. Most metals contain very small amounts of impurities and their surfaces are nonhomogenous. They are composed of arrays of microcells with anodic and cathodic microareas. Therefore, exposure of a metal to an aqueous solution permits chemical reductions and oxidations to take place.

The overall corrosion reaction can be formulated in single chemical reactions. Table 11 lists some of these reactions along with pertinent values of electromotive force, emf. Generally, the larger the potential, the greater the tendency of the reaction to proceed. (Fair, Geyer, and Okum, 1971).

For a positive emf, the reaction tends to proceed in the direction shown in Table 11. Large positive values do not necessarily imply rapid corrosion. Negative values imply the reaction will

TABLE 11

CORROSION REACTIONS WITH CORRESPONDING EMF

REACTION [a]	$E^{o}(25^{o}C)$ VOLTS
$Mg(s) + 2H+ = Mg++ + H_2(g)$	+2.37
$Zn(s) + 2H+ = Zn++ + H_2(g)$	+0.76
$Zn(s) + H_2O = ZnO(s) + H_2(g)$	+0.42
$Zn(s) + \frac{1}{2} O_2(g) = ZnO(s)$	+1.65
$Fe(s) + 2H+ = Fe++ + H_2(g)$	+0.41
$Fe(s) + \frac{1}{2} O_2(g) + 2H+ = Fe++ + H_2O$	+1.77
$Fe(s) + H_2O + \frac{1}{2} O_2(g) = Fe(OH)_2(s)$	+1.27
$Cu(s) + 2H+ = Cu++ + H_2(g)$	-0.34
$Cu(s) + \frac{1}{2} O_2(g) = CuO(s)$	+0.66
$Cu(s) + \frac{1}{2} O_2(g) + H_2O = Cu(OH)_2(s)$	+0.62
$Au(s) + 3/2H_2O + 3/4\ O_2(g) = Au(OH)_3(s)$	-0.23

SOURCE: G. M. Fair, J. C. Geyer, and D. A. Okun, Elements of Water Supply and Wastewater Disposal (New York: John Wiley and Sons, Inc., 1971), p. 491.

[a]Here (s) stands for solid and (g) for gas.

not proceed under the conditions described. Both oxidation and reduction reactions can be involved.

Reactions associated with the existence of microcells are illustrated in Figure 2, using iron as an example. (Fair, Geyer, and Okun, 1971).

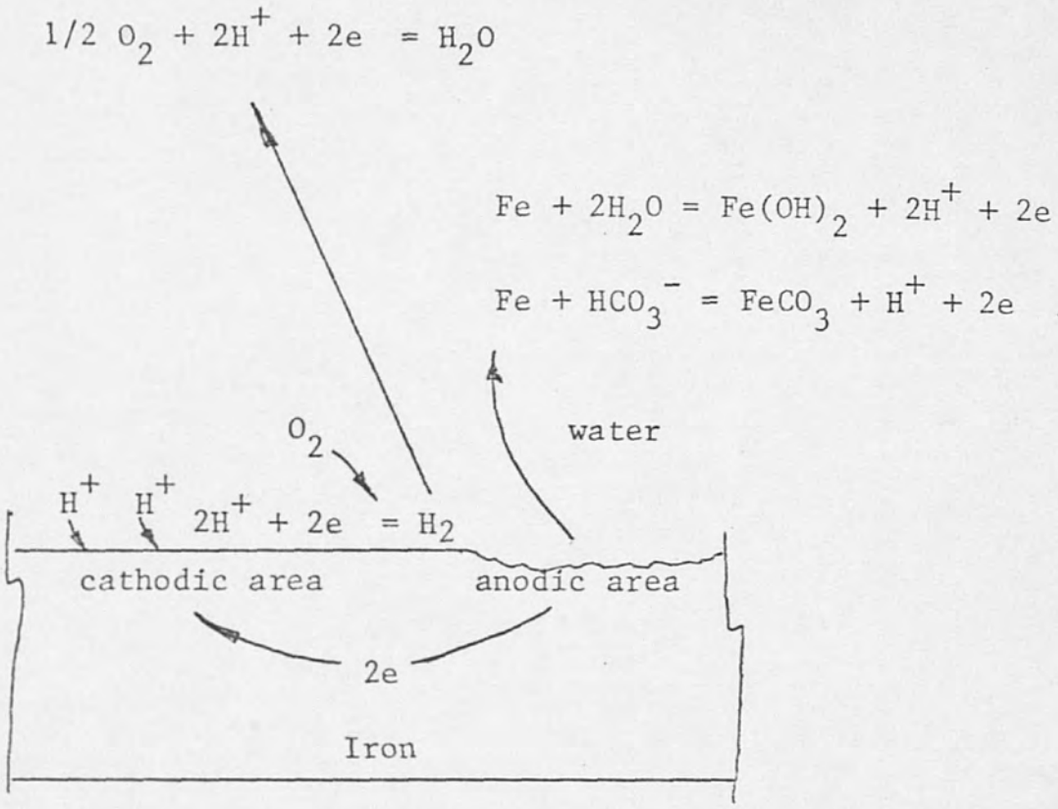


Fig. 2. Corrosion cell on the surface of iron in water.

SOURCE: G. M. Fair, J. C. Geyer, and D. A. Okun, Elements of Water Supply and Wastewater Disposal (New York: John Wiley and Sons, Inc., 1971), p. 492.

Contact between unlike metals or the existence of areas of similar unlike oxidation potentials in the same metal usually promote corrosion. The anodic metal or the area with the highest oxidation potential corrodes. The cathodic metal or area does not corrode. The behaviors of different metals may be gauged from a galvanic series that takes into account the environmental conditions normally encountered in water as shown in Table 12.

In water pipes, the rate of corrosion decreases with time because of the accumulation of rust or similar oxidation products on the pipe interior.

TABLE 12

GALVANIC SERIES OF METALS AND ALLOYS

Corroded (anodic or least noble)	Magnesium Zinc Aluminum Steel or Iron Cast Iron Lead Tin Brasses Copper Chromium-iron Silver Graphite
Protected (cathodic or most noble)	Gold Platinum

SOURCE: G. M. Fair, J. C. Geyer, and D. A. Okun, Elements of Water Supply and Wastewater Disposal (New York: John Wiley and Sons, Inc., 1971), p. 493.

Electrolytes such as chloride and sulfate promote corrosion because their peptizing action destroys protective films. (Fair, Geyer, Okum, 1971).

Types of Corrosion

Types of corrosion found in metal pipes are summarized by Holler, (1974) as follows:

1. Uniform Attack: The water reacts with the metal resulting in a uniform depth of penetration of the metal over the entire surface.

This type of corrosion is normally caused by acid solutions. Water with a high dissolved salts content and a high electrical conductivity will also give a uniform corrosion attack.

A surface which is covered with a uniform deposit will probably undergo a reasonable uniform type of attack. However, a deposit such as calcium carbonate resulting from hard water will reduce the rate of attack to almost zero.

2. Pitting: This is the most serious form of localized attack because the depth of penetration usually approximates the diameter of the corroded area. Even though the amount of metal corrosion may be very small, pitting often results in the perforation of the pipe. The size of the pits may range from shallow-hemispherical ones to pin-hole size in which the depth of penetration is much greater than the diameter.

Pitting is not clearly understood. It begins with a small anodic area and a large cathodic area. The rate of attack at the anode is a function of the conductivity of the water and the cathodic and anodic polarization.

3. Tuberculation: In tuberculation, mounds of corrosion products form on the surface of the metal from the corrosion processes occurring on the surface. These mounds of corrosion product are associated with pitting and overlie anodic areas where localized attack is taking place. Because of the size and numbers of the

mounds, the frictional resistance to flow is increased and the water carrying capacity of the pipe is greatly reduced. The mounds appear as tubercules, resulting in the name tuberculation.

The mounds found in steel or cast-iron water mains have a hard outer crust of brown hydrated ferric oxide and an inner layer of black magnetic or green rust. This crust physically separates the anionic area of the pit from the outside area where the oxygen reduction takes place.

Sulfates and chlorides concentrate within the pits, which results in a slightly acidic solution irrespective of the pH of the water outside. The oxygen concentration in the tubercule is about zero. The acidity tends to increase the rate of attack by providing a secondary cathodic reaction with the liberation of hydrogen. Tuberculation in copper and copper alloys is rare.

4. Exfoliation: This type of corrosion can occur with 80/20 or 70/30 cupro-nickel in high-pressure-feed water heaters. Severe corrosion results with a scale consisting of copper and nickel oxides in the same proportion as the metals present in the alloy. The scale grows and eventually flakes off.

5. Waterline Attack: This is localized corrosion which takes place at a 3-phase boundary-water-metal-air-such as would occur at a waterline.

There are two sources of corrosion; the easy access of O_2 to the

metal surface through the thin meniscus region, and the difficult access of solution to the surface because of the crevice formed between the air-liquid surface and the metal-liquid surface. The larger access of O_2 to this region creates a concentration cell where the meniscus area is cathodic with respect to the rest of the surface.

5. Crevice Attack: The area inside a crevice has a limited access of electrolyte which results in a corrosion concentration cell because of differences in salt, hydrogen ions, or oxygen concentrations. Crevices are formed where metal pipes are joined or make contact with one another or another material.

6. Dezincification: Brass can be selectively corroded by soft water which contains CO_2. As a result, the brass looses its zinc and is converted to a porous mass of soft, brittle copper. The same process can occur with bronze in which it loses its tin; this is called destannification.

7. Corrosion Erosion: Intense, localized corrosion can occur by the combined action of corrosion and mechanical abrasion due to turbulence in the water. This type of attack includes both impingment attack and cavitation.

Impingement attack results from the localized breakdown of a protective layer by suspended solids, gas bubbles, or by turbulence in the water. Impingement attack can occur at the entrances to pipes, sharp bends, near deposits, or where pipe diameters change

suddenly. Copper is very susceptible to this type of corrosion.

Cavitation attack occurs under turbulent flow conditions and is a serious form of severe and rapid wastage of metal. It is caused by vibration and the formation and collapse of vapor-filled cavities at the water-metal surface where sudden pressure changes occur. Pump impellers and valves usually have this type of corrosion.

8. Galvanic Corrosion: Galvanic cells arise in water distribution systems from the use of dissimilar metals for piping. As an example, copper home-distributor pipes are commonly connected to cast-iron or steel water mains. The result is a bimetallic couple and corrosion occurs at the junction of the two metals.

Corrosion of Selected Metals

Most corrosion problems are associated with relatively soft waters which contain dissolved oxygen. Normally, hard water is less corrosive than water softened by lime treatment or ion exchange or naturally soft waters, particularly when dissolved oxygen is present. (Larson, 1966).

Aggressive potable waters can produce corrosion with steel, iron, galvanized (zinc-coated) steel, lead, copper, and most commercially used alloys.

The following sections deal with the corrosion of specific metals by potable water. (Obrecht & Pourbax, 1967).

Iron

Water and metallic iron may not be simultaneously stable. If corrosion control is not applied, iron may corrode forming a ferrous solution (red water).

Ferric oxide is responsible for the corrosion of iron in water, leading to the formation of craters covered with tubercles of rust.

Corrosion control in large diameter iron or cast-iron pipes can be accomplished by proper application of nontoxic impervious coatings and cement linings. Chemical control of iron-steel corrosion can be accomplished by: (1) lowering the potential to reach the area of immunity by bringing the steel in contact with the zinc (galvanizing) or by using zinc or magnesium alloys; (2) raise the potential into the area of passivation, aerating the water to obtain a sufficiently protective oxide film.

Iron pickup due to corrosion is quite rapid. Davy (1953) reported that Independence and Cuba City, Wisconsin had dramatic increases in iron-pickup in the distribution lines. Table 13 gives analysis of Cuba City water, which was considered a typical condition. (Davy, 1953).

Zinc

Zinc corrosion is a serious problem as zinc will be corroded by pure water. Corrosion of zinc occurs at an electric potential of about -.8 volts which is lower than the critical protective

TABLE 13

ANALYSIS OF CUBA CITY, WISCONSIN WATER

PARAMTER	RAW WATER	WATER IN DEAD END OF DIST. SYSTEM
Total Hardness-PPM	312	312
Methyl orange alkalinity-PPM	295	295
Free carbon dioxide	37	37
Iron-PPM	0.1	2.6
pH	7.2	7.2

SOURCE: P. S. Davy, "Red Water and its Prevention," Journal of the American Water Works Association 45 (January, 1953): 15, Table 5.

potential for iron (-.6 volts). Therefore, in the case of galvanized pipes, corrosion of zinc will lead to a cathodic protection of the eventually bared underlying iron.

Temperatures higher than 60° C (140°F) can lead to a reversal of the electromotive force of the iron-zinc couple. This has led to serious pitting problems in galvanized hot water tanks of certain mineral contents. Galvanized steel or wrought-iron pipe will generally be satisfactory for warm and cold waters but will pit if the water temperature exceeds 140°F.

Patterson and Banker (1968) have produced the graph presented in Figure 3 showing the effect of dissolved solids on the life of galvanized iron piping:

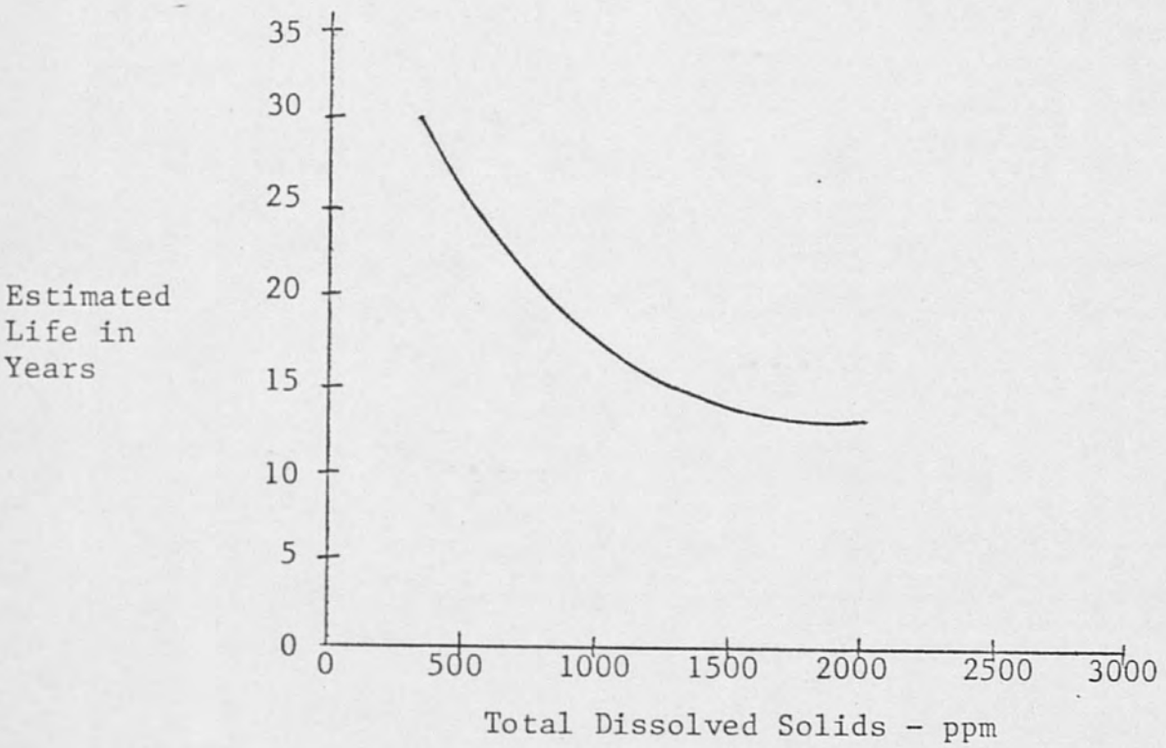


Fig. 3. The effect of dissolved solids on the life of galvanized iron piping.

SOURCE: W. L. Patterson and R. F. Banker, "Effects of Highly Mineralized Water on Household Plumbing and Appliances," Journal of the American Water Works Association 60 (September, 1968): 1061, Figure 1.

Lead

Soft waters will severely corrode lead because of the high solubility of lead oxide. Lead pipes should not be used for soft drinking waters, although they may sometimes be used for hard, scale-forming waters. Craun and McCabe (1975) have done research on the water system in Boston which uses lead pipes in various areas as previously discussed.

Copper

There are two primary sets of chemical conditions that can cause corrosion of copper: (1) A soft water with a low pH can produce corrosion in which there is fairly uniform reduction of tube thickness. The rate of attack is so slow that the tubing very rarely fails in its lifetime, but the copper that goes into solution can cause the water to develop a metallic taste, can spoil the taste of beverages, and if ingested in sufficient quantities, can cause nausea. (2) A high concentration of carbon dioxide generally with some dissolved oxygen present produces pitting and consequent perforation of the copper tube, but does not result in significant amounts of copper going into solution. Uhlig (1963) found that oxidizing agents or nonoxidizing agents such as carbonic acid together with an oxidizing agent, dissolved oxygen, can produce pitting. Campbell (1950) reported that carbon residues formed during tube manufacture by thermal decomposition of the drawing lubricants causes pitting of copper in hard waters ($CaCO_3$ conc. 100 ppm). Rambow and Holmgren (1966) reported on an incident in California in which copper leaks were reported in newly-built homes at the rate of about 15/month approximately 3 months after a reservoir and hydropneumatic tank system had been installed to service the development. The source was well water and its analysis is presented as follows:

calcium	225 ppm
magnesium	40 ppm

sodium	160 ppm
sulfate	525 ppm
chloride	170 ppm
bicarbonate	360 ppm
TDS	1500 ppm
hardness	735 ppm
pH	7.1
free CO_2	36 ppm

It was found that the probable cause of corrosion was the combined presence of free carbon dioxide and dissolved oxygen, possibly aggravated by the high TDS content of the water. The well water at the source contained partially no dissolved oxygen, but the DO rose in the hydropneumatic tank to approximately 3 ppm. Approximately 220 leaks in the development were reported in a 1.75 year period.

Hatch (1961) stated an instance of a hot-water line in Pittsburgh failing due to pitting after 3-4 years of service. The water temperature was 180-200°F and the water was a lime-soda-softened surface source with the following average composition:

total hardness (as $CaCO_3$)	100 ppm
total alkalinity (as $CaCO_3$)	30 ppm
sulfate concentration	150 ppm
chloride concentration	18 ppm
pH = 8.5	

The high temperature combined with the relatively high pH producing a hard, dense scale, approximately 1/16 inch in thickness. Numerous pits developed and the line began to leak. Cruse and Pomeroy (1974) listed examples in southern California where pitting has occurred.

Hatch (1961) reported of a motel whose copper water lines suffered impingement attack due to excessive velocities in the lines.

Hatch also reported of impengement attack in the recirculating hot-water system of a hospital using a municipal water supply.

Holler (1974) stated that copper is attacked very slightly by distilled water in which case copper ions are leached into solution.

Dissolved copper also has an accelerative action on the corrosion of the more anodic metals that the copper-containing water may attack. Usually this is of little concern for most metals in the water distribution system, however, zinc (such as in galvanized steel), and aluminum are much more susceptible than steel to the deleterious action of dissolved copper.

Hatch (1961) shows the influence of dissolved copper on the corrosion of zinc and aluminum by Pittsburgh tap water (pH=6.5, T=35^{o}C) as presented in Figure 4. A concentration of .1 ppm copper resulted in a fivefold increase in the corrosion rate of zinc. It also caused a localization of attack and marked pitting in the zinc pipe. The dissolved copper caused an even more accelerated attack on the aluminum than on the zinc.

Corrosion of Metal Pipes in New York

The New York City Board of Water Supply performed a long-range evaluation on corrosion of various types of metal pipes carrying potable water (Geld & McCaul, 1975).

The board has done corrosion tests on metal samples of

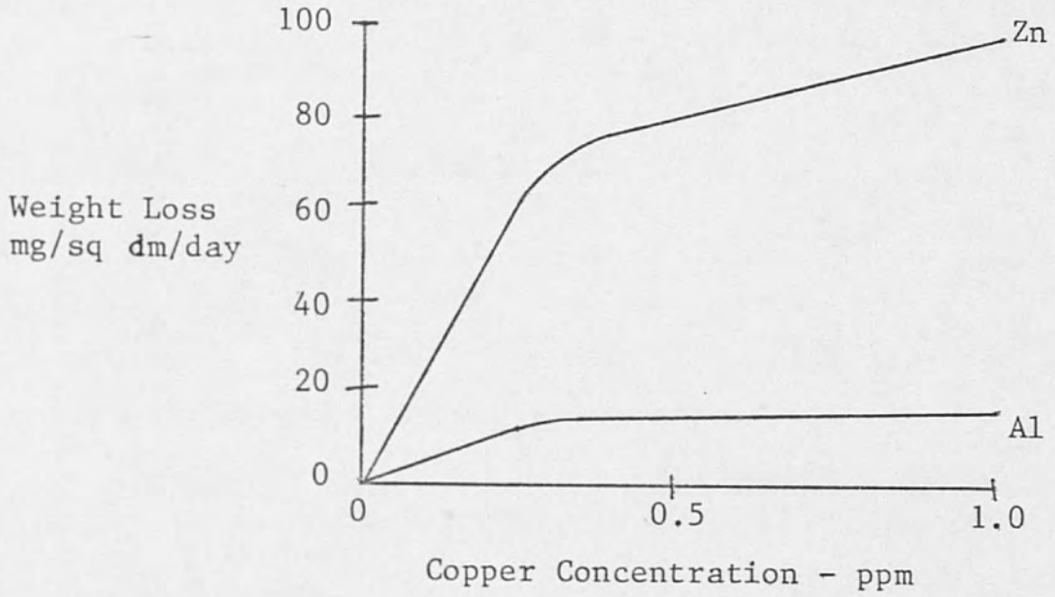


Fig. 4. The effect of dissolved copper concentration on the corrosion of zinc and aluminum.

SOURCE: G. B. Hatch, "Unusual Cases of Copper Corrosion," Journal of the American Water Works Association 53 (November, 1961): 1418, Figures 1 and 2.

various shapes and sizes over 15 years from 1960 to 1975. The specimens were suspended at room temperature in capped quart jars filled with relatively soft, quiescent reservoir water which was changed every 6 weeks. These conditions were meant to simulate the semistagnant water found in structures such as leaf-gate grooves, stop-shutter grooves, and risers. Periods of immersion were up to 15 years. The results of the water's corrosion on the metals are shown in Table 14.

Methods of Corrosion Control

Corrosion can be controlled by placing a protective coating

TABLE 14

THE RESULTS OF CORROSION OF WATER ON VARIOUS METALS

METAL	OBSERVED EFFECTS
Aluminum bronze and magnesium bronze	Significant local corrosion such as pitting and cracks
Nickel-copper	Numerous instances of severe pitting accompanied by copper-plug formation at the edges and on the faces
Stainless steel	Very little corrosion
Ungalvanized wrought iron	A relatively low rate of corrosion with no significant pitting
Galvanized iron	Significant corrosion which indicates the galvanizing did not offer cathodic protection

SOURCE: I. Geld and C. McCaul, "Corrosion in Potable Water," Journal of the American Water Works Association 67 (October, 1975): 549-551.

on the interior pipe surface. Protective coatings fall into two categories: (1) coatings applied before pipe installation; (2) coatings applied to the pipe in place through control of the chemistry of the water carried through the pipe.

Coatings applied to the pipe interior before installation can

be mortar or enamel, coal tar, cement and zinc. (Larson, 1966). Patterson (1978) reported these pre-applied coatings to be subject to failure with aggressive water.

Frye (1974) reported an eastern Philadelphia water company to have had very good experience with epoxy-phenolic-lined 30 inch force mains. Construction costs were lower and high Hazen-Williams coefficients were obtained.

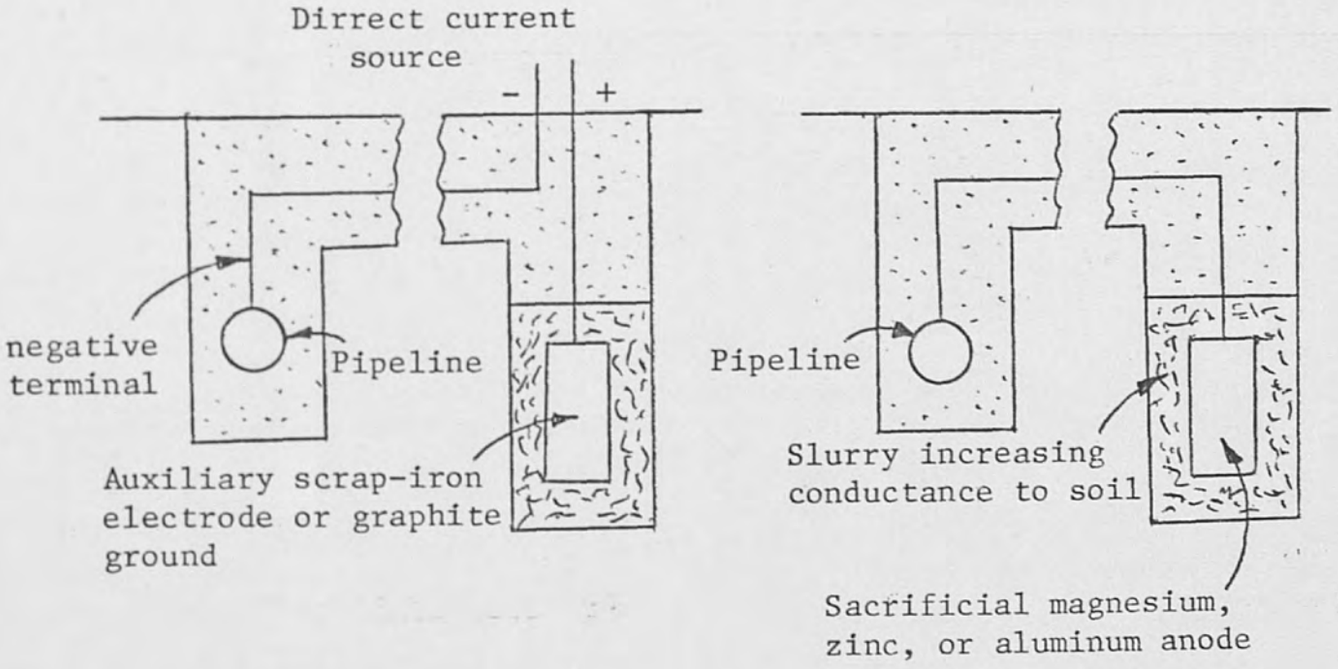
Applying and maintaining coatings in previously installed pipe requires permanent and closely controlled chemical additions. Paterson (1978) reported the best example of in-place control is the adjustment of pH of water of moderate calcium carbonate content. It is desired to maintain the pH near the saturation point of the calcium carbonate. This technique results in the deposition of a hard, impervious and adherent calcium carbonate coating on the interior pipe surface. Paterson (1978) also reported that effective calcium carbonate protection can be provided only when the water contains an alkalinity of at least 50 mg/l as $CaCO_3$, and an equal amount of calcium, expressed as $CaCO_3$.

Larson (1966) also reported that calcium carbonate deposition is generally considered the most applicable form of chemical control of corrosion. Corrosion control by deposition of $CaCO_3$ films was discussed by Merrill and Sanks, (1977, 1978).

Other chemical control procedures may include simple pH adjustment and the addition of silicates and phosphates. Lane, Larson, and Schulsky (1977) reported on silicate treatment of hot water in galvanized piping. They concluded that silicate treatment decreases

corrosion, with optimum silicate treatment appearing to be a complement of pH and silica dosage (the lower the pH, the higher the SiO_2 dosage) and is influenced by water quality paramaters such as calicum, magnesium, alkalinity, chloride and sulfate. Corrosion can also be controlled by electrical methods as discussed below.

Cathodic protection as shown in Figure 5 can be used. In Figure 5(a) direct-current electricity is used to feed electrons into the pipe and render it cathodic. In Figure 5(b) a metal with a higher emf is introduced into the system to become a sacrifical anode and be corroded. (Fair, Geyer, and Okun, 1971).



(a) Auxiliary Anode and Impressed Voltage

(b) Sacrificial Anode Forming Galvanic Cell

Fig. 5. Cathodic protection.

SOURCE: G. M. Fair, J. C. Geyer and D. A. Okun, Elements of Water Supply and Wastewater Disposal, (New York: John Wiley and Sons, Inc., 1971), p. 495.

Corrosion can also be reduced by creating resistence to the flow of electrical currents by (1) inserting insulating couples or connectors between dissimilar metals to prevent the generation of galvanic currents and (2) using insulating joints in water mains to oppose the flow of stray electrical currents. (Fair, Geyer, and Okun, 1971).

Heavy Metals in Wastewater

Any heavy metals present in domestic and industrial waste will eventually end up in the sewage treatment plant. These metals can concentrate in the sludge and may lead to operational problems and sludge disposal problems. The maximum allowable effluent discharge concentrations for heavy metals are given by Shambaugh and Melnyk (1978) and are presented in Table 15.

TABLE 15

MAXIMUM ALLOWABLE DISCHARGE CONCENTRATIONS FOR HEAVY METALS

METAL	LIMIT (µg/1)
Lead	50
Cadmium	10
Zinc	5000
Manganese	50
Arsenic	50
Barium	1000
Chromium	50
Mercury	2
Selenium	10
Silver	50
Copper	1000

SOURCE: P. B. Melnyk and R. L. Shambaugh, "Removal of Dichloramine and Ammonia by Granular Carbon," Journal of the Water Pollution Control Federation 50 (January, 1978): 113, Table 1.

Aerobic Processes

The aerobic, completely mixed biological treatment process has been shown to have a much greater capability for long-term removal of heavy metal ions than the anaerobic process. This type of process also shows a greater toxicant removal ability than a plug flow aerobic process. (Neufeld and Hermann, 1975).

Cheng et al. (1975), indicated that metal uptake by the biomass in an activated sludge process is characterized by a very rapid phase of 3 to 10 minutes followed by a long-term, slow, uptake phase. Metal is taken up by the biomass through the formation of metal-organic complexes. However, excess metal concentrations may precipitate out in addition to sludge uptake.

Metal uptake by the biomass depends on several factors such as pH and the concentration of organic matter and metals in the system. The overall uptake is increased with higher initial concentraions of metal ions and the concentration of mixed liquor suspended solids in the sludge. Normally, the uptake capacity increases with increasing pH, up to a value at which metal hydroxide precipitation occurs. Neufeld et al., (1977) reported that the uptake of metals by activated sludge followed a decreasing order of Pb > Cd > Hg > Cr(+3) > Cr(+6) > Zn > Ni.

The affinity of the biomass for metal ions is much greater than that of competing organics in the supernatant which results in large-scale accumulation of heavy metals by activated sludge.

Anaerobic Process

Anaerobic digestion is very vulnerable to excessively high

heavy metal loadings. Rudolphs and Zeller (1932) found heavy metals to be more toxic than light metal ions in anaerobic digestion. Barth et al., (1967) found that high removals of heavy metals by primary and secondary wastewater treatment resulted in elevated levels of heavy metals in digested feed sludges which were 6 to 37 times the metal concentrations in the plant influent.

Heavy metals in the precipitated form are of little consequence to biological systems in terms of toxicity. The toxicity of heavy metals in anaerobic digestion depends on the chemical form of the metal. Hayes and Theis (1978) presented metal toxicity limits for anaerobic digestion as presented in Table 16.

TABLE 16

HEAVY METAL TOXICITY LIMITS FOR ANAEROBIC DIGESTION

HEAVY METAL	STEP-FED TOXIC LIMIT mg/l	PULSE-FED TOXIC LIMIT mg/l
Cr(+3)	260	< 200
Cr(+6)	420	< 180
Cu	70	< 50
Ni	30	> 30
Cd	20	> 10
Pb	340	> 250
Zn	600	< 1700

SOURCE: T. D. Hayes and T. L. Theis, "The Distribution of Heavy Metals in Anaerobic Digestion," Journal of the Water Pollution Control Federation 50 (January, 1978): 66, Table 4.

The disruption of anaerobic digestion by heavy metals results in a lowering of gas production. Hayes and Theis (1978) found the

order of decreasing toxicity on a weight-weight or molar basis to be Ni > Cd > Pb > Cr > Zn. Cadmium was found to produce no toxic or inhibitory effects.

Control strategies resulting in a decrease of metal association with the biomass will minimize the impact of heavy metals on anaerobic digestion. The addition of more precipitating agents such as sulfide and operating at maximum pH should result in increased tolerance to heavy metals.

Removal Techniques for Heavy Metals

There are various removal techniques available for heavy metals in water and wastewater which are summarized in Tables 17 and 18.

The EPA (1978) determined the effects of different coagulants on percent heavy metal removal verses pH of treated water. The results are summarized in Table 18.

Hayes and Theis (1978) reported that if the metals in the digested sludge from a sewage treatment plant were in a precipitated phase, removal could be achieved through a mild acidification treatment followed by solids removal. For organically bound metals, a prolonged exposure under more extreme acid conditions would be required to bring about removal and recovery.

DeWalle et al., (1979) showed that a completely mixed anaerobic filter is effective in removing heavy metals with effectiveness increasing with heavy metal concentration. The metals were precipitated as sulfides, carbonates, and hydroxides and were removed from the filter as a slurry in the bottom solids collection device.

TABLE 17

COMMON HEAVY METAL REMOVAL TECHNIQUES

CONTAMINANT	MOST EFFECTIVE METHODS
Arsenic	
As+3	Ferric sulfate coagulation, pH 6-8
	Alum coagulation, pH 6-7
	Excess lime softening
	Oxidation before treatment required
As+5	Ferric sulfate coagulation, pH 6-8
	Alum coagulation, pH 6-7
	Excess lime softening
Cadmium	Ferric sulfate coagulation, pH > 8
	Lime softening
	Excess lime softening
Calcium	Lime softening
Chromium	
Cr+3	Alum coagulation, pH 7-9
	Ferric sulfate coagulation, pH 6-9
	Excess lime softening
Cr+6	Ferric sulfate coagulation, pH 7-9.5
Copper	Ion exchange, evaporation and electrolysis
	Precipitation with lime pH 9-10.3
Iron	Aeration
	Filtration
	Lime precipitation
Lead	Ferric sulfate coagulation, pH 6-9
	Alum coagulation, pH 6-9
	Lime softening
	Excess lime softening
Magnesium	Lime softening
Nickel	Lime precipitation, pH 10
	Filtration
	Ion exchange
Zinc	Lime precipitation
	Filtration

SOURCES: U. S. Environmental Protection Agency, Manual of Treatment Techniques for Meeting the Interim Primary Drinking Water Regulations (Washington, D. C., 1977); M. Sittig, Pollutant Removal Handbook (New York: Noyes Data Corporation, 1973).

TABLE 18

REMOVAL OF INORGANIC CONTAMINANTS BY VARIOUS COAGULANTS

TYPE OF COAGULANT	CONTAMINANT	MOST EFFECTIVE pH RANGE	% REMOVAL*
Iron	Pb	6-9.5	99+
	As+5	6-8	98
	As+3	6.5-8.5	60
	Cr+3	6-9.5	99
	Cd	8-9	96
Alum	Pb	6-9.5	99+
	As+5	6-6.5	95
	Cr+3	7-9	96
	Cd	9	95
Lime Softening	Pb	8.5-11.5	99+
	As+5	11	99+
	As+3	11-11.5	80
	Cr+3	11	99+
	Cd	8.5-11.5	99+

SOURCE: U. S. Environmental Protection Agency, Manual of Treatment Techniques for Meeting the Interim Primary Drinking Water Regulations (Washington, D. C., 1977).

* % Removal is dependent on Raw Water quality as well as coagulant, contaminant and pH.

CHAPTER III

METHODOLOGY

Water samples were collected, prepared for analysis, and run through a plasma spectrometer to determine their heavy metal content.

Sample Collection

Water samples were collected from the UCF potable intake wells and various campus buildings. Composite influent and effluent wastewater samples were also collected from the UCF sewage treatment plant. Running water samples were collected at each well and building and in some instances standing and hot water samples were collected. All running samples were taken after flushing the water lines for approximately 5 minutes to insure that the distribution pipes were adequately flushed.

Types and locations of samples taken from each sampling point are summarized in Table 19.

Sample Preparation

Samples were prepared for heavy metal analysis according to Standard Methods for Examination of Water and Wastewater: (14th ed., 1976).

TABLE 19

DESIGNATION OF POTABLE WATER AND SEWAGE SAMPLE LOCATIONS COLLECTED FROM UCF CAMPUS BUILDINGS AND SEWAGE TREATMENT PLANT

LOCATION OF SAMPLE	SAMPLE DESIGNATION	TYPES OF SAMPLES COLLECTED
Utility Plant	U-S	standing
	U-R	running
Fine Arts	F-R	running
Biology	B-R	running
Physical Plant	P-S	standing
	P-R	running
Chemistry	C-R	running
ROTC	R-R	running
Village Center Complex	V-R	running
Physical Education	PE-R	running
Cafeteria	CA-H	hot
	CA-R	running
Computer	CO-H	hot
	CO-R	running
Library	L-R	running
Administration	A-R	running
Child Care Center	CC-R	running
Engineering	E-R	running
Central Receiving	CR-R	running
Education	ED-H	hot
	ED-R	running
Sewage Plant	S-H	hot
	S-R	running
Dorm A	DA-R	running
Dorm B	DB-H	hot
	DB-R	running
Dorm C	DC-R	running
Dorm D	DD-R	running
Well #1	W1	running
Well #2	W2	running
Well #3	W3	running
Well #4	W4	running
Sewage Plant influent	WW1	composite
Sewage Plant effluent	WW2	composite
Activated sludge	WW3	grab

The most widely used method to analyze water samples for heavy metal content involves atomic absorption techniques.

In atomic absorption analysis the sample is atomized by a flame. The chemical bonds between the molecules are broken, enabling individual atoms to freely float in the sample area and absorb radiation characteristic of it in that state. The wavelength bands that any particular element can absorb are very narrow and specific. The measurement of an element is determined by the amount a given wavelength of light is absorbed from a light beam directed through the flame into a monochromator and to a detector-meter recorder system. The amount of light absorbed is directly proportional to the concentration of the metal ion in the atomized sample. Atomic absorption is used by the cities of Chicago (Willey, et al., 1972) and New York (Egan and Peterson, 1972) for metal analysis of their water supplies and both cities have reported excellent results.

A more recent technique which is still in the developmental stage involves the use of plasma spectrophotometry to measure heavy metals in water samples. During the course of this study, the plasma spectrophotometer, Spectraspan III by MIC, was used.

The flame temperature in this instrument reaches 6000-7000^{o}K. The abundance of accessible energy from the plasma eliminates much of the chemical interferences which often plague flame atomic absorption/emission instruments. The high temperature enables direct flame analysis of such non-metals as boron and phsophorous along with refractory type metals. A greater linear range is often

achieved by measuring elemental concentrations using the ionized spectral lines available with this high excitation energy.

The Spectraspan III has an inverted 'Y' configuration, using two graphite anodes and one tungsten cathode. The carbon electrodes burn slowly, increasing long term stability.

The Spectraspan III is operated on argon gas. Benefits of using argon gas are reduced sample oxidation, the gas is non-toxic and non-explosive, and reduced operating costs.

The instrument accepts only liquid samples which are fed into a nebulizer by a pump. This results in even sample uptake, which is approximately 2.0 ml/minute. The liquid is converted to an aerosol by the nebulizer at an efficiency of about 20%. All samples were analyzed for the following heavy metals: Zinc, Cadmium, Arsenic, Nickel, Copper, Iron, Lead, Chromium, and Aluminum. Calcium and Magnesium were also measured for selected sample sets.

CHAPTER IV

RESULTS AND DISCUSSION

Drinking water and sewage samples were collected, prepared, and analyzed for heavy metal content. The data collected was analyzed and presented. Conclusions and recommendations were developed and presented.

Water Analyses

Water samples collected from various intake wells and buildings on the UCF campus were analyzed. The pH and calcium and magnesium concentrations for water samples collected are shown in Table 20.

The pH of the running water samples varied between 7.6 and 8.0. The standing and hot water samples' pH varied between 7.8-8.0 and 7.7-8.40, respectively. The magnesium and calcium concentrations for the running water samples varied between 6.77-5.60 mg/1 and 44.1-34.5 mg/1, respectively. The hot water samples showed a magnesium and calcium range of 7.50-5.98 mg/1 and 40.0-37.3 mg/1, respectively. The standing water samples' magnesium concentration ranged from 6.04 to 6.15 mg/1, and the calcium concentration ranged from 43.4 to 42.3 mg/1. Well #4 showed the highest magnesium concentration of 6.77 mg/1 and the lowest calcium concentration of 34.5 mg/1. It can be concluded that the UCF potable water is moder-

TABLE 20

pH VALUES AND CALCIUM AND MAGNESIUM CONCENTRATIONS IN WATER SAMPLES COLLECTED FROM THE UCF CAMPUS

Building	PH values on		Magnesium conc. (mg/1) on	Calcium conc. (mg/1) on
	2/22	3/22	5/1	5/1
U-S	7.85	7.78	6.15	42.3
U-R	7.73	7.78	6.24	40.9
F-R	7.85	7.85	6.13	40.8
B-R	7.80	7.80	5.91	39.2
P-S	7.95	7.99	6.04	43.4
P-R	7.99	7.99	6.06	44.1
C-R	7.65	7.91	6.18	43.4
R-R	7.70	7.71	5.60	37.8
V-R	7.75	7.78	5.84	39.9
PE-R	7.81	7.80	5.76	39.5
CA-R	7.71	7.80	6.05	39.9
CA-H	--	8.4	5.98	39.9
CO-R	7.90	7.98	6.06	40.7
CO-H	--	7.78	7.50	37.3
L-R	7.79	7.90	6.13	43.2
A-R	7.75	7.73	6.10	43.1
CC-R	7.85	7.80	6.19	40.9
E-R	7.78	7.85	----	----
ED-R	7.8	7.74	6.14	44.1
ED-H	--	7.99	6.32	38.6
CR-R	7.71	7.61	5.68	38.2
S-R	7.90	7.88	6.03	40.8
S-H	--	7.80	6.25	40.0
DA-R	7.70	7.70	6.14	43.1
DB-R	7.71	7.78	6.08	40.1
DB-H	--	7.71	6.07	40.2
DC-R	7.65	7.71	5.82	38.8
DD-R	7.73	7.84	5.79	38.7
W1	7.75	7.83	6.08	39.8
W2	7.70	7.89	5.96	42.1
W3	7.80	7.90	6.12	42.9
W4	7.90	7.93	6.77	34.5

ately hard and the pH is slightly basic.

The heavy metal concentrations are presented in Tables 21 through 29. The tables show concentrations of zinc, cadmium, arsenic, nickel, copper, aluminum, iron, lead, and chromium in water samples collected from running, standing, and hot water. The following observations were made concerning the heavy metal content in the potable water samples:

Zinc

All four intake wells show low average zinc concentrations with the highest concentration reported in Well #3 of .017 mg/1. Most of the running water samples collected from the distribution system seem to show higher concentrations of zinc than those detected in the intake well water. Also, running water from the Fine Arts Building showed the largest pick up of zinc with .432 mg/1 reported. The zinc concentrations found in the water samples are well below the 5 mg/1 standard for zinc and do not pose any health problems. Zinc is a beneficial and essential element in human metabolism.

The standing water samples showed high concentrations of zinc indicating that zinc is picked up from the distribution system when the water is allowed to stand for a period of time.

The hot water samples from various buildings were generally higher in zinc concentration than from samples collected from cold water lines. Sources of zinc pick up in the water distribution system may be galvanized pipe and hot water tanks.

TABLE 21

ZINC* CONCENTRATIONS IN SAMPLES COLLECTED FROM WATER AND WASTEWATER SYSTEMS ON THE UCF CAMPUS

Building	Sample Type	CONCENTRATION (mg/l) on 4/4	4/18	4/23	5/1	$\bar{X}$	σ
U-S	std.	---	4.52	3.30	3.21	3.677	.732
U-R	run.	.026	.042	.035	.031	.034	.007
F-R	run.	.038	.036	.031	.013	.030	.011
B-R	run.	.021	.065	.048	.025	.040	.021
P-S	std.	.075	.029	----	.055	.053	.023
P-R	run.	.007	.009	.054	.010	.020	.023
C-R	run.	.041	.018	.024	.074	.039	.025
R-R	run.	.002	.008	----	.008	.006	.003
V-R	run.	.017	.015	.034	.024	.023	.009
PE-R	run.	.010	.001	.045	.008	.016	.020
CA-R	run.	.012	.011	.035	.010	.017	.012
CA-H	hot	.019	.007	.027	.028	.020	.010
CO-R	run.	.070	----	.088	.019	.059	.036
CO-H	hot	.073	.066	.095	.085	.080	.013
L-R	run.	.004	.010	.030	.011	.014	.011
A-R	run.	.010	.016	.019	.012	.014	.004
CC-R	run.	.361	.602	.405	.361	.432	.115
E-R	run.	.028	.020	.064	.013	.031	.023
ED-R	run.	.044	.042	.091	.035	.053	.026
ED-H	hot	.050	.001	.057	.015	.031	.027
CR-R	run.	.011	.011	.018	.011	.013	.004
S-R	run.	.121	.164	.185	.115	.146	.034
S-H	hot	.290	.262	.149	.003	.176	.130
DA-R	run.	.001	.010	.013	.017	.010	.007
DB-R	run.	.010	.002	.010	.010	.008	.004
DB-H	hot	.004	.008	.021	.009	.011	.007
DC-R	run.	.010	.016	----	.010	.012	.003
DD-R	run.	.029	.005	.014	.023	.018	.011
W1	run.	.009	.015	.009	.011	.011	.003
W2	run.	0.0	.002	.049	.010	.015	.023
W3	run.	.011	.010	.037	.011	.017	.013
W4	run.	.006	.011	.036	.012	.016	.013
WW1	comp.	.972	.129	.319	.170	.398	.392
WW2	comp.	.069	.071	.056	.039	.059	.015

*The secondary standard for Zinc in drinking water is 5 mg/l.

TABLE 22

CADMIUM* CONCENTRATIONS IN SAMPLES COLLECTED FROM WATER AND WASTEWATER SYSTEMS ON THE UCF CAMPUS

Building	Sample Type	CONCENTRATION (mg/l) on 4/4	4/18	4/23	5/1	$\bar{X}$	σ
U-S	std.	----	.006	.002	.004	.004	.002
U-R	run.	.003	.002	.001	.002	.002	.001
F-R	run.	.001	.001	0.0	.002	.001	.001
B-R	run.	.001	.002	.001	.001	.001	.001
P-S	std.	.001	.002	.002	.002	.002	.001
P-R	run.	.001	.002	0.0	.002	.001	.001
C-R	run.	0.0	.002	.001	.002	.001	.001
R-R	run.	.004	.002	.001	.002	.002	.001
V-R	run.	.001	.001	0.0	.001	.001	.001
PE-R	run.	0.0	.003	0.0	.008	.003	.004
CA-R	run.	.001	.002	.001	.002	.002	.001
CA-H	hot	0.0	0.0	.001	.002	.001	.001
CO-R	run.	.003	.003	.002	.002	.003	.001
CO-H	hot	.001	.001	.001	.001	.001	0.0
L-R	run.	.003	.002	.002	.002	.002	.001
A-R	run.	.001	.001	.002	.003	.002	.001
CC-R	run.	0.0	.002	.001	.002	.001	.001
E-R	run.	.001	.001	.001	.003	.002	.001
ED-R	run.	.001	.002	0.0	.002	.001	.001
ED-H	hot	.002	.001	.001	.003	.002	.001
CR-R	run.	.001	.003	0.0	.002	.002	.001
S-R	run.	.003	.002	0.0	.001	.002	.001
S-H	hot	.001	.003	0.0	.002	.002	.001
DA-R	run.	.004	.001	.001	.001	.002	.002
DB-R	run.	.001	.003	0.0	.001	.001	.001
DB-H	hot	.004	.002	.001	.001	.002	.001
DC-R	run.	.001	.003	.001	.001	.002	.001
DD-R	run.	0.0	.001	.001	.001	.001	.001
W1	run.	.001	.002	.001	.003	.002	.001
W2	run.	.005	.001	0.0	.001	.002	.002
W3	run.	.001	.001	0.0	.002	.001	.001
W4	run.	.001	.003	.001	.002	.002	.001
WW1	comp.	.003	.002	.006	.008	.005	.003
WW2	comp.	.002	.001	.002	.001	.002	.001

*Maximum permissible concentration of Cadmium in drinking water is .01 mg/l.

TABLE 23
ARSENIC* CONCENTRATIONS IN SAMPLES COLLECTED FROM
WATER AND WASTEWATER SYSTEMS ON THE UCF CAMPUS

Building	Sample Type	CONCENTRATION (mg/l) on 4/4	4/18	4/23	5/1	$\bar{X}$	σ
U-S	std.	----	.025	.067	.083	.058	.030
U-R	run.	.034	.024	.047	----	.035	.012
F-R	run.	.031	.015	.127	.127	.075	.060
B-R	run.	.023	.005	.051	.069	.037	.029
P-S	std.	.003	.012	.081	.099	.049	.048
P-R	run.	.018	.015	----	.046	.026	.017
C-R	run.	.018	.009	0.0	.020	.012	.009
R-R	run.	.038	.013	.080	.111	.061	.044
V-R	run.	.003	.017	.050	.066	.034	.029
PE-R	run.	.038	.003	0.0	.072	.028	.034
CA-R	run.	.042	.008	.024	.088	.041	.035
CA-H	hot	.015	0.0	.047	.065	.032	.030
CO-R	run.	.036	.007	.082	.065	.048	.033
CO-H	hot	.020	.010	.033	.077	.035	.030
L-R	run.	.030	.017	.111	.103	.065	.049
A-R	run.	.009	.011	.076	.142	.060	.063
CC-R	run.	0.0	.013	.043	.100	.039	.044
E-R	run.	0.0	.015	.016	----	.010	.009
ED-R	run.	.031	.022	.051	.088	.048	.029
ED-H	hot	.037	.066	.043	.119	.051	.048
CR-R	run.	.018	.027	.099	.098	.061	.044
S-R	run.	.030	.013	.087	.065	.049	.033
S-H	hot	.031	.007	.071	.136	.061	.056
DA-R	run.	.040	.011	.062	.110	.056	.042
DB-R	run.	.014	.007	.097	.089	.052	.048
DB-H	hot	.040	.004	.040	.112	.049	.045
DC-R	run.	.020	.026	.067	.072	.046	.027
DD-R	run.	0.0	.003	.058	.102	.041	.049
W1	run.	.015	.014	.072	.101	.051	.043
W2	run.	.039	0.0	.120	.084	.061	.052
W3	run.	.018	.002	.113	.125	.065	.063
W4	run.	.006	.026	.069	.062	.041	.030
WW1	comp.	.047	.016	.072	.108	.061	.039
WW2	comp.	.056	.059	.029	0.0	.036	.028

*Maximum permissible concentration of Arsenic in drinking water is .05 mg/l.

TABLE 24

NICKEL* CONCENTRATIONS IN SAMPLES COLLECTED FROM WATER AND WASTEWATER SYSTEMS ON THE UCF CAMPUS

Building	Sample Type	CONCENTRATION (mg/l) on 4/4	4/8	4/23	5/1	$\bar{X}$	σ
U-S	std.	----	.012	.028	.016	.019	.008
U-R	run.	.003	.008	.008	.009	.007	.003
F-R	run.	.018	.014	.005	.006	.011	.006
B-R	run.	.015	.008	.009	.005	.009	.004
P-S	std.	.015	.010	.009	.011	.011	.003
P-R	run.	.008	.008	----	.005	.007	.002
C-R	run.	.014	.007	.007	.006	.009	.004
R-R	run.	.003	.006	.004	.006	.005	.002
V-R	run.	.007	.008	.007	.006	.007	.001
PE-R	run.	.020	.010	.007	.005	.011	.007
CA-R	run.	.018	.009	.007	.005	.010	.006
CA-H	hot	.008	.003	.003	.006	.005	.002
CO-R	run.	.003	.010	.006	.007	.007	.003
CO-H	hot	.009	.008	.011	.005	.008	.003
L-R	run.	.003	.006	.004	.006	.005	.002
A-R	run.	.009	.006	.010	.006	.008	.002
CC-R	run.	----	.006	.003	.005	.005	.002
E-R	run.	----	.008	.009	.008	.008	.001
ED-R	run.	.016	.008	.005	.005	.009	.005
ED-H	hot	.004	.005	.005	.008	.006	.002
CR-R	run.	.010	.010	.005	.008	.008	.002
S-R	run.	.004	.008	.005	.005	.006	.002
S-H	hot.	.013	.012	.007	.007	.010	.003
DA-R	run.	.004	.006	.008	.006	.006	.002
DB-R	run.	.011	.010	.005	.005	.008	.003
DB-H	hot.	.005	.010	.013	.008	.009	.003
DC-R	run.	.001	.013	.004	.006	.006	.005
DD-R	run.	.010	.008	.008	.005	.008	.002
W1	run.	.008	.008	.003	.007	.008	.002
W2	run.	.004	.008	.005	.004	.005	.002
W3	run.	.003	.009	.009	.006	.007	.003
W4	run.	.001	.010	.003	.006	.005	.004
WW1	comp.	.012	.012	.031	.019	.019	.009
WW2	comp.	.007	.005	.008	.003	.006	.002

*There is no MCL limit on nickle in drinking water.

TABLE 25

COPPER* CONCENTRATIONS IN SAMPLES COLLECTED FROM WATER AND WASTEWATER SYSTEMS ON THE UCF CAMPUS

Building	Sample Type	CONCENTRATION (mg/l) on 4/4	4/8	4/24	5/1	$\bar{X}$	σ
U-S	std.	----	.013	.012	.014	.013	.001
U-R	run.	.006	.006	.006	----	.006	0.0
F-R	run.	.113	.098	.103	.087	.100	.011
B-R	run.	.978	.067	1.37	.588	.751	.557
P-S	std.	1.31	1.50	1.67	1.29	1.43	.158
P-R	run.	.045	.049	.043	.037	.044	.005
C-R	run.	.116	----	.159	.090	.122	.035
R-R	run.	.018	.016	.021	.018	.018	.002
V-R	run.	.484	.358	.710	.300	.463	.182
PE-R	run.	.037	.021	.026	----	.028	.008
CA-R	run.	.071	.075	.075	.067	.072	.004
CA-H	hot	.169	.104	.215	.309	.199	.086
CO-R	run.	.095	.120	.131	.108	.114	.016
CO-H	hot	.741	.682	1.04	.309	.693	.300
L-R	run.	.155	.074	----	.324	.184	.128
A-R	run.	.080	.104	.104	.069	.089	.018
CC-R	run.	.174	.138	.147	.162	.155	.016
E-R	run.	.122	.211	.456	.225	.254	.142
ED-R	run.	.085	.110	.166	.094	.114	.036
ED-H	hot	.584	----	.642	.777	.668	.099
CR-R	run.	.107	.113	.133	.130	.121	.013
S-R	run.	.061	.055	.080	.051	.062	.013
S-H	hot	.217	.246	.212	.206	.220	.018
DA-R	run.	.238	.202	.252	.214	.227	.023
DB-R	run.	.202	.125	.216	.179	.181	.040
DB-H	hot	.624	.535	.507	.571	.559	.050
DC-R	run.	.240	.253	.259	.214	.242	.202
DD-R	run.	.151	.227	.216	.037	.158	.087
W1	run.	.005	.008	.007	.021	.010	.007
W2	run.	.006	.006	.005	.003	.005	.001
W3	run.	.003	.005	.007	.007	.006	.002
W-4	run.	.001	.013	.002	.006	.006	.005
WW1	comp.	.111	.095	.080	.223	.130	.063
WW2	comp.	.030	.026	.029	.020	.026	.005

*The secondary standard for Copper in drinking water is 1 mg/l.

TABLE 26

ALUMINUM* CONCENTRATIONS IN SAMPLES COLLECTED FROM WATER AND WASTEWATER SYSTEMS OF THE UCF CAMPUS

Building	Sample Type	CONCENTRATION (mg/l) on				$\bar{X}$	σ
		4/4	4/18	4/24	5/1		
U-S	std.	----	.104	.109	.026	.140	.047
U-R	run.	.052	.111	.211	.271	.161	.098
F-R	run.	.363	.129	.114	.188	.199	.114
B-R	run.	.362	----	.199	.207	.256	.092
P-S	std.	.185	.086	.092	.272	.159	.088
P-R	run.	.183	.086	.119	.208	.149	.056
C-R	run.	.347	.073	.207	.207	.209	.112
R-R	run.	.049	.121	.116	.285	.143	.100
V-R	run.	.184	.080	.026	.267	.187	.074
PE-R	run.	.375	.071	.204	.200	.213	.125
CA-R	run.	.362	.088	.216	.189	.214	.113
CA-H	hot	.014	.014	.061	.215	.076	.095
CO-R	run.	.048	.166	.059	.216	.122	.082
CO-H	hot	.180	.088	.059	.217	.136	.075
L-R	run.	.048	.085	.060	.219	.103	.079
A-R	run.	.184	.135	.069	.185	.143	.055
CC-R	run.	.168	.086	.057	.204	.129	.069
E-R	run.	.179	.091	.200	.193	.166	.051
ED-R	run.	.347	.109	.119	.247	.206	.113
ED-H	hot	.051	.085	.111	.234	.120	.080
CR-R	run.	.188	.105	.119	.278	.173	.079
S-R	run.	.050	.092	.110	.210	.116	.068
S-H	hot	.352	.078	.210	.198	.210	.112
DA-R	run.	.048	.070	.214	.268	.150	.108
DB-R	run.	.184	.073	.114	.173	.136	.052
DB-H	hot	.049	.069	.214	.278	.153	.111
DC-R	run.	.191	.117	.075	.208	.148	.063
DD-R	run.	.172	.073	.213	.288	.187	.090
W1	run.	.185	.091	.070	.243	.147	.081
W2	run.	.048	.082	.116	.187	.108	.059
W3	run.	.045	.085	.122	.196	.112	.064
W4	run.	.176	.102	.055	.173	.127	.059
WW1	comp.	.498	.442	.405	.479	.456	.041
WW2	comp.	.251	.300	.289	.224	.266	.035

*There is no MCL limit on Aluminum in drinking water.

TABLE 27

IRON*CONCENTRATIONS IN SAMPLES COLLECTED FROM WATER AND WASTEWATER SYSTEMS OF THE UCF CAMPUS

Building	Sample Type	CONCENTRATION (mg/l) on 4/4	4/18	4/24	5/1	$\bar{X}$	σ
U-S	std.	----	.120	.090	.158	.123	.034
U-R	run.	.118	.161	.217	.474	.243	.160
F-R	run.	.525	.206	.130	.235	.274	.173
B-R	run.	----	.115	.113	.226	.151	.065
P-S	std.	.324	.139	.103	.205	.193	.097
P-R	run.	.317	.144	.224	.261	.237	.073
C-R	run.	.472	.132	.139	.259	.251	.159
R-R	run.	.119	.222	.215	.262	.205	.061
V-R	run.	.327	.154	.192	.195	.217	.076
PE-R	run.	----	.124	.154	.228	.169	.054
CA-R	run.	.450	.121	.170	.257	.250	.145
CA-H	hot	.152	.135	.065	.265	.154	.083
CO-R	run.	.166	.183	.211	.299	.215	.059
CO-H	hot	.409	.168	.511	.101	.300	.198
L-R	run.	.123	.154	.098	.263	.159	.073
A-R	run.	.333	.197	.176	.218	.231	.070
CC-R	run.	.273	.190	.119	.204	.197	.063
E-R	run	.222	.137	.200	.154	.178	.039
ED-R	run.	----	.141	.134	.171	.149	.020
ED-H	hot	.081	.034	.118	.256	.122	.096
CR-R	run.	.353	.144	.151	.204	.213	.097
S-R	run.	.101	.165	.138	.234	.160	.056
S-H	hot	.578	.100	.136	.541	.339	.256
DA-R	run.	.091	.130	.172	.212	.151	.052
DB-R	run.	.345	.111	.144	.227	.207	.104
DB-H	hot	.098	.111	.179	.219	.152	.057
DC-R	run.	.308	.548	.136	.269	.315	.172
DD-R	run.	.318	.123	.164	.277	.221	.092
W1	run.	.286	.145	.168	.323	.231	.087
W2	run.	.086	.123	.129	.225	.141	.059
W3	run.	.133	.146	.172	.238	.172	.047
W4	run.	----	.070	.040	.061	.057	.015
WW1	comp.	.617	.868	.343	.567	.599	.215
WW2	comp.	.097	.163	.104	.073	.109	.038

*The secondary standard for Iron in drinking water is 3 mg/l.

TABLE 28

LEAD* CONCENTRATIONS IN SAMPLES COLLECTED FROM WATER AND WASTEWATER SYSTEMS OF THE UCF CAMPUS

Building	Sample Type	CONCENTRATION (mg/l) on 4/4	4/18	4/24	5/1	$\bar{X}$	σ
U-S	std.	----	.113	.046	.082	.080	.03-
U-R	run.	.051	.098	.042	.085	.069	.02?
F-R	run.	.074	.100	.038	.068	.070	.025
B-R	run.	.070	.080	.043	.070	.066	.01?
P-S	std.	.055	.093	.033	.078	.065	.026
P-R	run.	.052	.086	.039	.069	.062	.02?
C-R	run.	.064	.083	.043	.071	.065	.01?
R-R	run.	.050	.091	.035	.080	.064	.026
V-R	run.	.053	.092	.044	.075	.066	.022
PE-R	run.	.081	.092	.040	.067	.070	.02?
CA-R	run.	.076	.090	.040	.069	.069	.021
CA-H	hot	.056	.101	.031	.072	.065	.029
CO-R	run.	.049	.018	.035	.071	.043	.022
CO-H	hot	.056	.091	.037	.064	.062	.022
L-R	run.	.048	.083	.033	.074	.060	.023
A-R	run.	.055	.091	.034	.069	.062	.02-
CC-R	run.	.120	.088	.031	.071	.078	.037
E-R	run.	.159	.085	.047	.073	.091	.048
ED-R	run.	.070	.098	.037	.069	.069	.025
ED-H	hot	.048	.078	.039	.080	.061	.021
CR-R	run.	.058	.103	.036	.079	.069	.029
S-R	run.	.050	.090	.036	.070	.062	.02-
S-H	hot	.068	.103	.046	.075	.073	.024
DA-R	run.	.051	.084	.042	.075	.063	.020
DB-R	run.	.057	.092	.034	.061	.061	.02-
DB-H	hot	.053	.084	.044	.079	.065	.020
DC-R	run.	.060	.111	.031	.070	.068	.033
DD-R	run.	.140	.083	.043	.082	.087	.040
W1	run.	.054	.093	.030	.089	.067	.030
W2	run.	.053	.085	.036	.061	.059	.020
W3	run.	.044	.097	.039	.071	.063	.027
W4	run.	.053	.102	.029	.065	.062	.030
WW1	comp.	.070	.088	.089	.105	.088	.01-
WW2	comp.	.060	.064	.062	.050	.059	.006

*The maximum permissible concentration of lead in drinking water is .05 mg/l.

TABLE 29

CHROMIUM* CONCENTRATIONS IN SAMPLES COLLECTED FROM WATER AND WASTEWATER SYSTEMS OF THE UCF CAMPUS

Building	Sample Type	CONCENTRATION (mg/l) on 4/4	4/18	4/24	5/1	$\bar{X}$	σ
U-S	std.	----	.011	.055	.012	.009	.004
U-R	run.	.007	.010	.021	.021	.015	.077
F-R	run.	.013	.010	.004	.011	.010	.004
B-R	run.	.020	.007	.010	.009	.012	.006
P-S	std.	.012	.007	.004	.010	.008	.004
P-R	run.	.010	.007	.031	.010	.015	.011
C-R	run.	.015	.007	.010	.013	.011	.004
R-R	run.	.006	.009	.007	.010	.008	.002
V-R	run.	.012	.008	.007	.016	.011	.004
PE-R	run.	.012	.007	.008	.011	.010	.002
CA-R	run.	.011	.007	.009	.009	.009	.002
CA-H	hot	.002	.006	.004	.016	.007	.006
CO-R	run.	.006	.010	.005	.011	.008	.003
CO-H	hot	.009	.010	.012	.010	.010	.001
L-R	run.	.006	.007	.003	.014	.008	.005
A-R	run.	.007	.008	.010	.010	.009	.002
CC-R	run.	0.0	.007	.004	.009	.005	.004
E-R	run.	0.0	.008	.009	.009	.007	.004
ED-R	run.	.015	.009	.006	.008	.010	.004
ED-H	hot	.016	.002	.007	.026	.013	.011
CR-R	run.	.004	.011	.007	.010	.008	.003
S-R	run.	.006	.008	.006	.009	.007	.002
S-H	hot	.019	.008	.008	---	.012	.006
DA-R	run.	.006	.010	.010	.010	.009	.002
DB-R	run.	.006	.008	.005	.011	.008	.003
DB-H	hot	.007	.007	.016	.009	.010	.004
DC-R	run.	.006	----	.003	.016	.008	.007
DD-R	run.	0.0	.006	.008	.011	.006	.005
W1	run.	.010	.007	.004	.013	.009	.004
W2	run.	.007	.005	.005	.011	.007	.003
W3	run.	.005	.005	.014	.014	.010	.005
W4	run.	.010	.010	.004	.014	.010	.004
WW1	comp.	.043	.153	.087	.041	.069	.056
WW2	comp.	.011	.016	.020	.008	.014	.005

*The maximum permissible concentration of chromium in drinking water is .05 mg/l.

Cadmium

All water samples collected averaged between 1 and 4 parts per billion in cadmium concentrations. The standing water samples averaged higher concentrations than the running water samples. Also, there was no significant difference between samples collected from hot water lines and those collected from cold water lines.

The measured cadmium concentrations were well below the .01 mg/l drinking water standards. Cadmium concentrations in the UCF water offer no danger to human health. Standing water samples' pick up of cadmium may be due to the use of zinc galvanized iron piping in which cadmium is a contaminant.

Arsenic

All four intake wells showed high arsenic concentrations, the highest being .065 mg/l from Well #3. Some of the running water samples collected from the distribution system showed higher arsenic concentrations than those detected in the well water. The standing water samples showed higher concentrations of arsenic than the running water samples from the same building.

There was no significant difference between samples collected from hot water lines and those collected from cold water lines. The maximum permissible concentration for arsenic in potable water is .05 mg/l. The arsenic concentrations may seem to be higher than the permissible concentrations, however, the measured levels were very near the spectrophotometer's detection limits for arsenic and probably errors in measurement could have occurred. Further investi-

gations of arsenic need to be completed.

Nickel

The intake wells showed low average nickel concentrations with the highest being .007 mg/l reported in Wells #1 and #3. There was no appreciable pick up of nickel in the running water samples. The Fine Arts Building showed the largest average concentration of .011 mg/l nickel. The standing water samples showed higher average concentrations than the running water samples.

There was no significant difference between samples collected from hot water lines and those collected from cold water lines. There is no drinking water standard for nickel concentrations in water. The nickel concentrations in the UCF drinking water do not present a health hazzard.

Copper

The intake wells show low average copper concentrations, the largest being .01 mg/l from Well #1. All running water samples collected from the distribution system showed higher concentrations of copper than those detected in the well water.

Both the standing and hot water samples showed higher copper concentrations than running samples collected from the cold water lines. The highest copper concentration reported was 1.43 mg/l from the Physical Plant standing sample.

With the exception of the standing water sample from the Physical Plant, no copper concentrations exceeded the drinking water standard of 1 mg/l and no health hazzards exist.

The major source of copper pick up in the distribution system

is probably copper tubing. Copper in solution enhances the corrosion of aluminum and to a lesser degree, zinc.

Aluminum

All four intake wells showed aluminum concentrations less than .147 mg/l which was detected in Well #1. Most of the running water samples collected from the distribution system seem to show higher concentrations of aluminum than those detected in the well water. Running water from the Cafeteria Building showed the largest pick up of average aluminum concentration of .214 mg/l reported.

There was no significant difference between standing and hot water samples as compared to running samples collected from cold water lines. There is no drinking water standard for aluminum concentrations in potable water. No health hazzards exist due to the aluminum concentrations in the UCF water.

Iron

All four intake wells showed average iron concentrations less than .231 mg/l which was detected in water samples from Well #1. Most running water samples collected from the distribution system showed higher concentrations of iron than those detected in the well water. Dorm C showed the highest average iron concentration of .315 mg/l.

The standing water samples showed less iron than the running water samples collected from the same building. This indicates that possibly the iron had precipitated out of solution during the time the water was standing in the pipe.

There was no significant difference between samples collected

from hot water lines and those collected from cold water lines.

With the exception of the running water sample from Dorm C and the hot water sample from the Computer Building, no other samples exceeded the .3 mg/l drinking water standard for iron. Iron is a necessary element for body metabolism and the UCF drinking water does not pose a health threat due to iron concentration.

The most probable source of iron pick up in the distribution system is the ductile iron piping used in the transmission lines.

Lead

All of the four intake wells showed concentrations with the highest of .067 mg/l detected from Well #1. Some of the running water samples collected from the distribution system showed higher lead concentrations than those detected in the well water. The Engineering Building showed the largest running water sample lead concentration of .091 mg/l.

Both the standing and hot water samples showed higher lead concentrations than the running cold water samples from the same buildings.

The maximum permissible concentration for lead in drinking water is .05 mg/l. The lead concentrations may seem to be higher than the permissible levels, however, the measured concentrations were very near the plasma spectrophometer's detection limits for lead. Therefore, probable errors in measurements may have occurred. Further investigations of lead need to be completed.

Chromium

The highest average chromium concentration reported from the

four intake wells was .01 mg/1 coming from Wells #3 and #4. The running water samples collected from the distribution system show virtually no increase in chromium concentrations over those detected in the well water. The largest concentration reported from a running water sample was .015 mg/1 coming from the Utility Plant and Physical Plant Buildings.

The standing water samples showed less average chromium concentrations than the running samples taken from the same building, possibly indicating chromium precipitation while the water was standing in the pipes.

The hot water samples from various buildings were generally higher in chromium concentration than from samples collected from cold water lines.

The chromium concentrations found in the water samples are well below the 0.05 mg/1 standard for chromium. Chromium concentrations in the UCF drinking water do not create any health hazzards.

Wastewater Analyses

Raw and final effluent samples from the UCF sewage treatment plant were analyzed. All samples were unfiltered and their pH values ranged from 7.4 to 7.6 for influent samples and 6.6 to 6.8 for effluent samples.

The average heavy metal concentrations for the influent and effluent samples are summarized in Table 30. It appears that the heavy metals which existed in the water distribution system were also detected in the influent samples and the concentrations followed the same general trend similar to concentrations in the water samples.

TABLE 30

ANALYSIS OF WASTEWATER SAMPLES FROM UCF SEWAGE TREATMENT PLANT

ELEMENT	AVERAGE CONCENTRATION (mg/1)		% REMOVAL	SLUDGE SOLIDS CONCENTRATION (mg/gm of Fixed Solids)	
	Influent	Effluent		4/13	4/26
Zinc	.398	.059	85.2	.982	2.721
Cadmium	.005	.002	60.0	.009	.023
Arsenic	.061	.036	41.0	----	----
Nickle	.019	.006	89.5	.015	.033
Copper	.130	.026	80.0	.987	2.623
Aluminum	.456	.266	41.7	2.159	6.934
Iron	.599	.109	81.8	4.379	13.360
Lead	.088	.059	33.0	.233	.682
Chromium	.069	.014	79.7	.097	.262

The concentrations in the effluent samples were considerably lower than those detected in the influent samples. It appears that most of the heavy metals were associated with suspended solids and were removed by settling from the final effluent. The percent removal varied between 33% for lead and 89.5% for nickel as shown in Table 30.

To determine the extent of the concentration of heavy metals in mixed liquor suspended solids, two sludge samples were collected from the sludge digestor tanks, filtered, dried at 103°C and fired at 550°C. The two samples showed total residue concentrations of 39106 ppm and 24373 ppm and the volatile residue was found to be 56% and 49% respectively, as shown in Table 31. The fixed fractions of the solids were digested and prepared for heavy metal analysis. The data is shown in Table 20 and indicates that concentrations of heavy metals in mixed liquor suspended solids followed a decreasing order for Fe, Al, Zn, Cu, Pb, Cr, and Cd.

TABLE 31

SOLIDS ANALYSIS OF ACTIVATED SLUDGE FROM
UCF WASTEWATER TREATMENT PLANT

SAMPLE	VOLUME ml	TOTAL RESIDUE ppm	FIXED RESIDUE ppm	% VOLATILE SUSPENDED SOLIDS	% FIXED SUSPENDED SOLIDS
1	100	39106	17309	56	44
2	100	24372	12451	49	51

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based on the data obtained from the heavy metal analyses of UCF drinking water and wastewater samples, the following conclusions were reached:

1. Water samples collected from the distribution system at UCF were slightly basic with pH between 7 and 8, and moderately hard.

2. Based on the average concentrations of heavy metals detected in the running water samples, the decreasing order of concentration was found to follow: Fe > Al > Cu > Pb > As > Zn > Cr > Ni > Cd.

3. There was none or scarce pick up of Cd, Ni, and Cr in the running water samples collected from the distribution system.

4. Standing water samples showed greater concentrations of Zn, Cd, As, Cu, and Pb, than running water samples from the same sampling point.

5. Hot water samples showed greater concentrations of Zn, Cu, Pb, and Cr than cold running water collected from the same sampling point.

6. It appeared that Fe and Cr concentrations in the

standing water were lower than the concentrations in the running water from the same sampling point. This was probably due to formation of limited protection coatings due to standing water in the pipe.

7. Most of the running and standing water samples collected showed higher concentrations of Zn, Cu, Al and Fe than detected in the well water, indicating corrosion in the distribution system. The Fine Arts and Utility Plant Buildings were found to have the highest Zn concentrations. The largest Cu concentrations were found in the Physical Plant and Biology Buildings. The Cafeteria and P.E. Buildings showed the highest concentrations of Al. Dorm C and the Fine Arts Building showed the largest pick-up of Fe.

8. Most of the elements measured were below the recommended standard for drinking water as specified by the U.S. Environmental Protection Agency. Verification of lead and arsenic concentrations is needed since the values measured were close to the Spectrospan III instrument detection limits.

9. The decreasing order of heavy metal concentrations in the wastewater influent samples collected from the UCF plant showed: Fe > Al > Zn > Cu > Pb > Cr > As > Ni > Cd. It appeared the wastewater samples followed the same general decreasing order similar to water samples.

10. Heavy metals in the influent wastewater samples were removed throughout the treatment processes. The efficiency of removal followed the following decreasing order: Ni > Zn > Fe > Cu > Cr >

Cd > Al > As > Pb. The removal efficiencies varied between 89.5 percent for Ni and 33 percent for Pb.

11. The metals removed were concentrated into the sludge solids. Two sludge samples were analyzed and the metal content per gram of fixed solids followed the following decreasing order: Fe > Al > Zn > Cu > Pb > Cr > Ni > Cd.

Recommendations

Initial investigation of heavy metal content in water and wastewater samples collected from the UCF systems was completed. Much information was obtained, however, the following additional studies were recommended:

1. The arsenic and lead concentrations in the UCF drinking water samples should be verified.

2. Additional standing and running water samples should be analyzed to investigate causes, effects and management practices for corrosion control.

3. Mass balance of heavy metals through wastewater treatment processes should be attempted. Also, physical, chemical and biological mechanisms involved in heavy metal removal should be investigated.

4. The impact of the sewage lagoon on heavy metal removal should be studied.

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